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Ubiquitous Actualization

Application Specific Networking Patterns

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Grappling with the "Opportunity"

Part I

The Superiority of Short Range Communication

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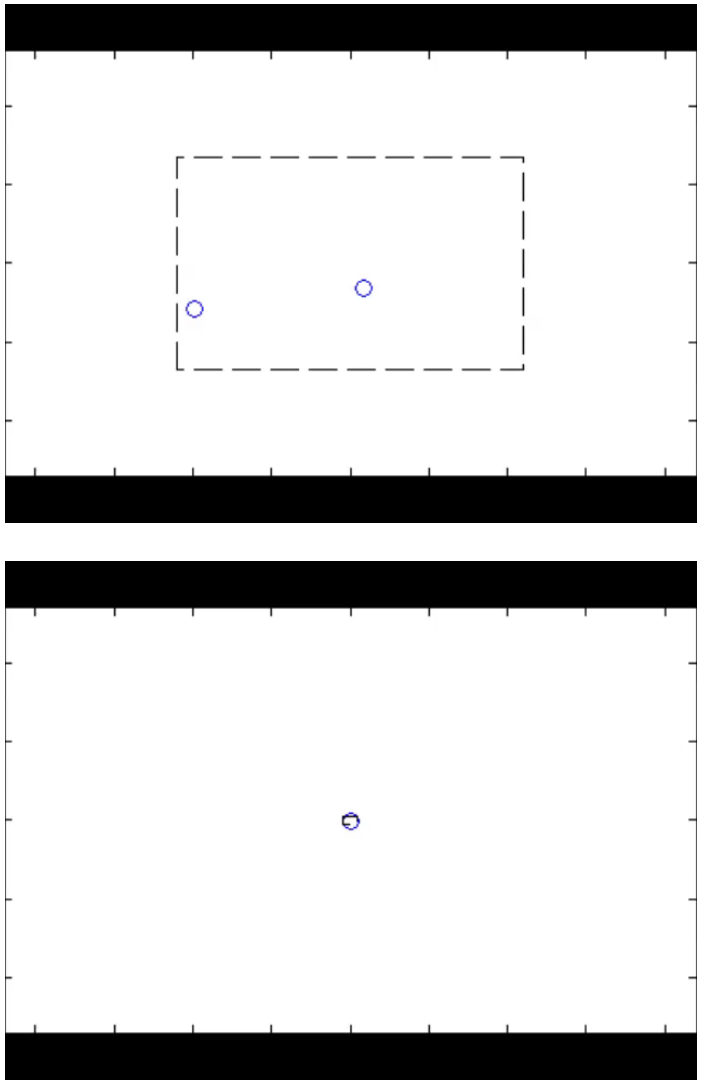
- **Units of network aggregate capacity are data-distance per time.**
  - e.g., bit-meters/sec.
- **Two extreme scaling scenarios:**
  - Constant area.
  - Constant density.
- **For constant area:**
  - Link range shrinks by $\sqrt{n}$.
  - Link capacity to remain constant.
- **For constant density:**
  - Link range remains constant.
  - Link capacity falls by $\sqrt{n}$.
- **In both cases:**
  - Aggregate capacity grows like $\sqrt{n}$.



The MANET Scaling Problem

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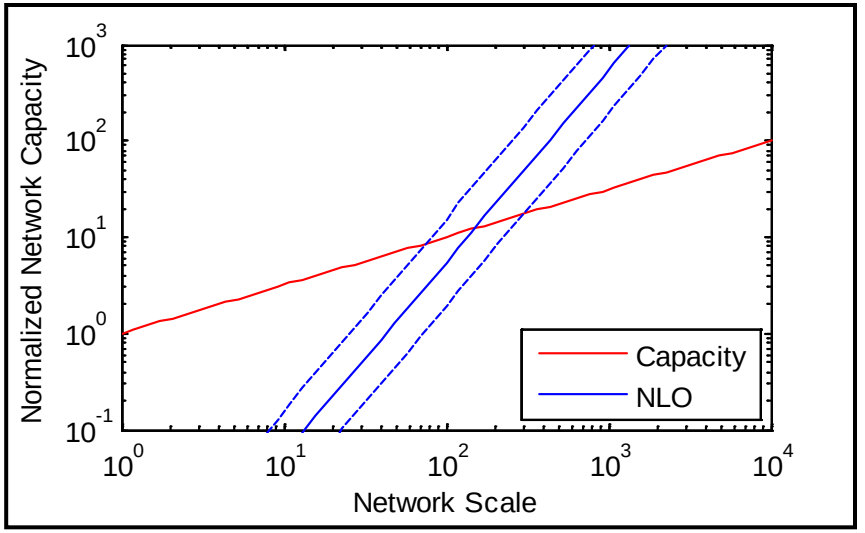
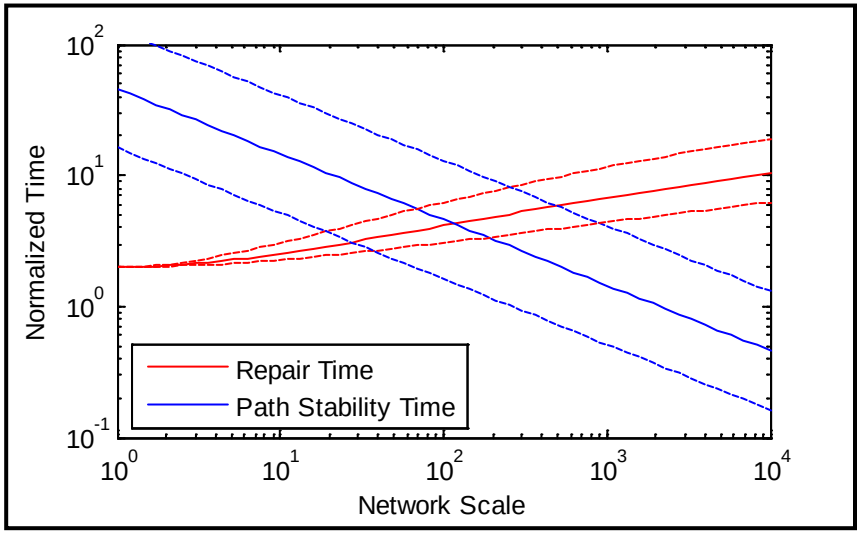
- **Attendance today likely implies a few shared beliefs:**
  - Traditional MANETs don't scale.
    - *i.e., the problem is not solved.*
  - Some MANET-like system could scale.
    - *i.e., there is still hope for a solution.*
- **Why do MANETs not scale?**
  - The complexity of maintaining the network is overwhelming.



- **The capacity implications of complexity are easy to quantify:**
  - Quantifying the mobility model is ad hoc; the rest is not.
- **Route repair time implications are harder to quantify.**
- **Other complexity affects can be identified and quantified.**



Is there Reason for Hope?

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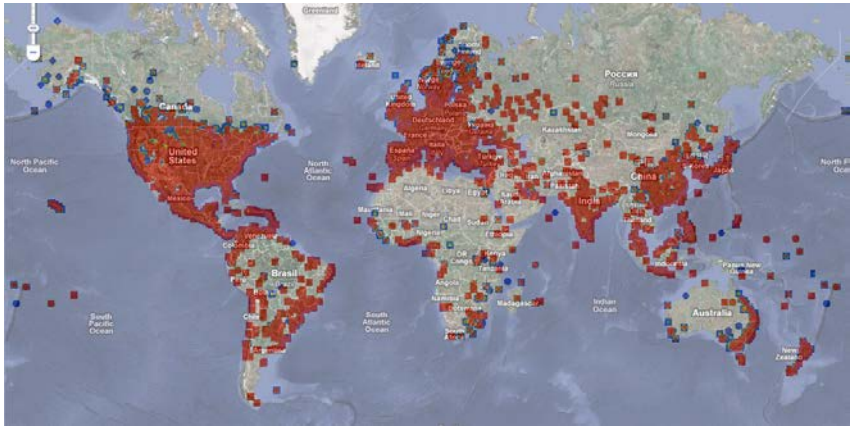
- **Because the prize is large …**
  - 10K nodes implies 100x the capacity.
  - Ultra flexible CONOPS.
- **… maybe this is self delusion …**



- **Conficker Worm:**
  - Used peer-to-peer networking to avoid capture of the control node (i.e., IP).
  - Seemed to scale to 10's of millions.
  - Avoided point-to-point routing
    - *Only supported flooding with pruning.*
- **Many examples from Wireless Sensor Networks (WSN).**

- **Caution: The degree of mobility in these examples is modest.**

Theoretical Result

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- **Is there a theoretical bound on networking layer overhead?**
  - Are we far from the performance limit?
  - Suggest rather algorithmic advanced or problem redefinition is needed.
- **Two recent papers:**
  - Consider the network state as a random process.
  - Use node location as a surrogate for network state.
  - Compute the capacity required for optimal dissemination of information.
- **Result:**
  - MANETs don't scale.
  - Complexity of knowing the network state grows faster than capacity.
- **Details:**
  - Simply knowing your neighbors misses by $O(\ln^{\gamma}(n))$.
    - γ *is a measure of locality of motion.*
  - If all nodes need all the information the miss is $O(n^{3/2})$ worse.
- **Node location as a proxy for network state:**
  - Equivalent for "glass table top" propagation model.
  - Overly optimistic for multipath.

Our Thinking

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- **Mobility is a fundamental change.**
  - It's a different problem.

- **In the absolute sense of the word, MANETs do *NOT* scale.**
  - Scaling of traditional MANETs is so poor as to cast doubt on their usefulness.
  - Scaling of non-traditional MANETs could be "close enough for practical purposes".

- **The practical limits of scaling are dominated by the information needs of the networking layer.**

Information Needs of the Networking Layer	Practical Limit
Global knowledge at all nodes	50 to 100
Distance sensitive knowledge	500 to 2K
Only knowledge of neighbors	5K to 40K

Realignment of the Problem

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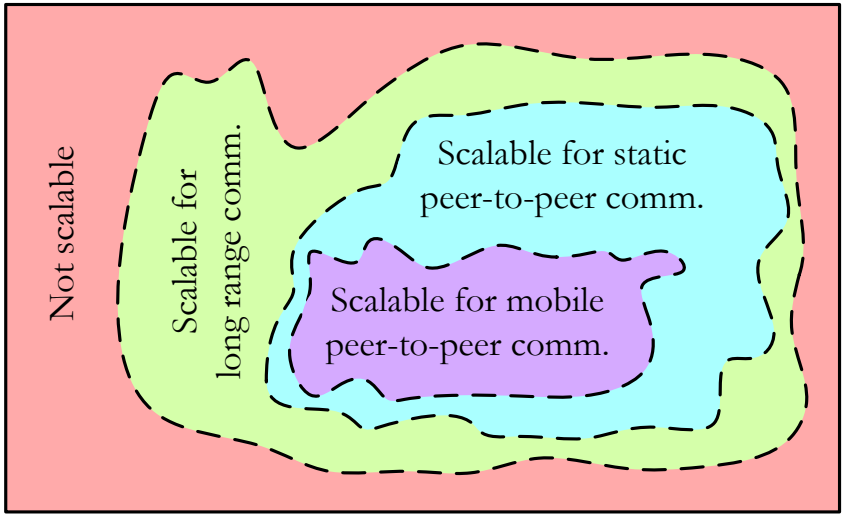
- **Consider Stove Pipe Systems (SPSs).**
  - Top to bottom vertical integration.
  - Application and networking combined.
    - *Assume everything is "*stove piped*": waveform, link management, data management, user interface …*
- **When can a particular SPS scale?**
  - … if implemented perfectly.
  - Depends on the application.
  - Not all applications will scale.
- **But some SPSs do scale, even in the presence of mobility.**



- **This implies that:**
  - The networking portion of these SPSs must scale.
  - The networking needs of these SPSs is less than fully general.

Success seems to depend on developing application motivated networking.

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Application Specific Networking Patterns (ASNPs) for MANETs

Part II

What do we mean by ASNP?

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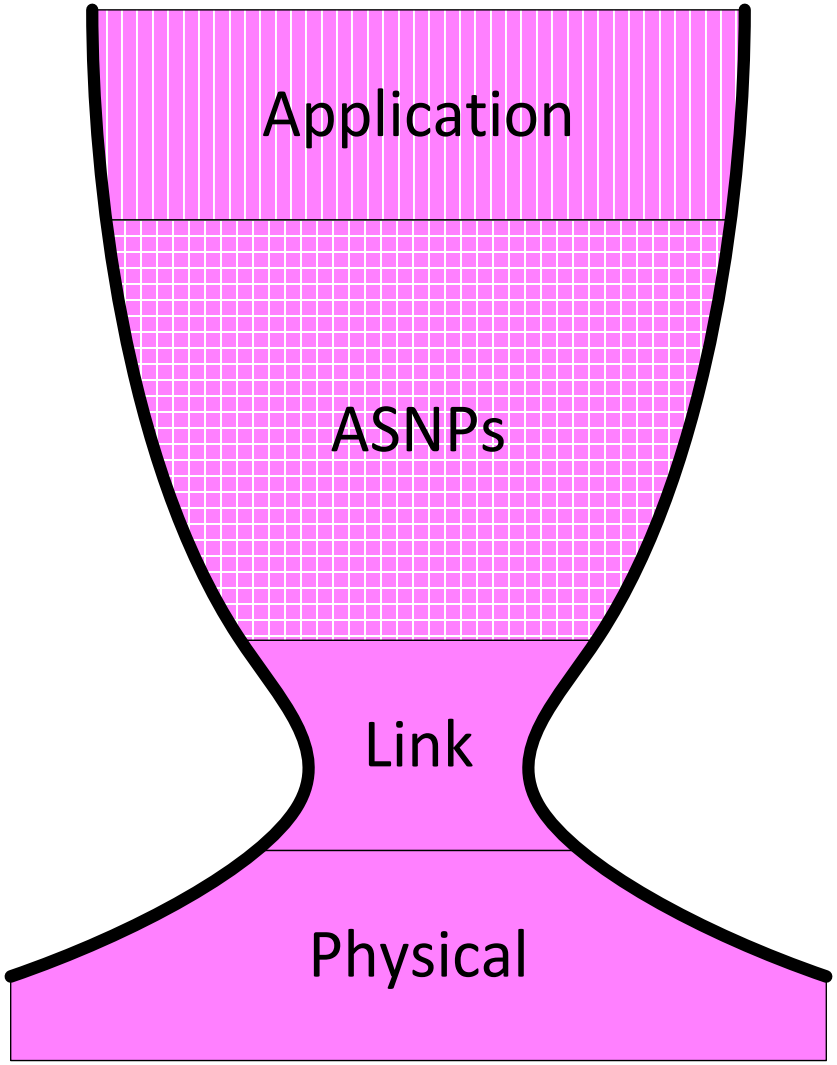
- **Intended to evoke the analogy to ASICs vs. general processors.**
  - Some loss of generality is traded for significant increases in performance.
- **Each ASNP will support a different networking pattern.**
- **Only highly scalable patterns.**
  - This implies no support for unlimited arbitrary point-to-point routing.
- **Applications will pick from a collections of reusable patterns.**
  - Applications may yield new patterns.
    - … *should not be the common case.*



Strategies for Scaling

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- **Variations on local traffic.**
  - Typically, support for non-local traffic would be limited.
  - Lower overhead, less efficient method could be used for non-local traffic.
- **Variations on flooding.**
  - Flooding is efficient if the data is needed by most of the affected nodes.
- **Maintain routing structures, but only for a limited set of routes.**
  - Maintenance complexity can be far less than for all-to-all routing.
- **Variations on virtual hierarchy.**
  - Bottom-up maintenance of routes to and from leaders and between leaders at the same level.
- **Strategically suboptimal routing.**
  - Maintaining minimally sufficient routes may be much lower overhead than maintain optimal routes.
  - Probably most useful when combined with other methods.
- **Delay tolerance.**
  - The complexity of sometimes knowing the route may be much less than always knowing the route.
- **Variations on random walks.**
  - Is not that inefficient if most nodes must be "checked" to get an answer.
  - Probably most useful as gradient influenced walk.
- **Variations on geographic routing.**

Link Layer Definition

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- All ASNPs are supposed to support two meta-MACs:

Always On:

- Traditional high power radio.
- Optimizes spectral efficiency.
- The key problem is to operate at a level of healthy congestion.

Low Duty Cycle:

- Traditional WSN system.
- Optimizes energy efficiency.
- Congestion is nearly ignorable.
  - At 1% of the spectral capacity, it is "easy" to avoid congestion.

The Router Abstraction Layer (RAL)

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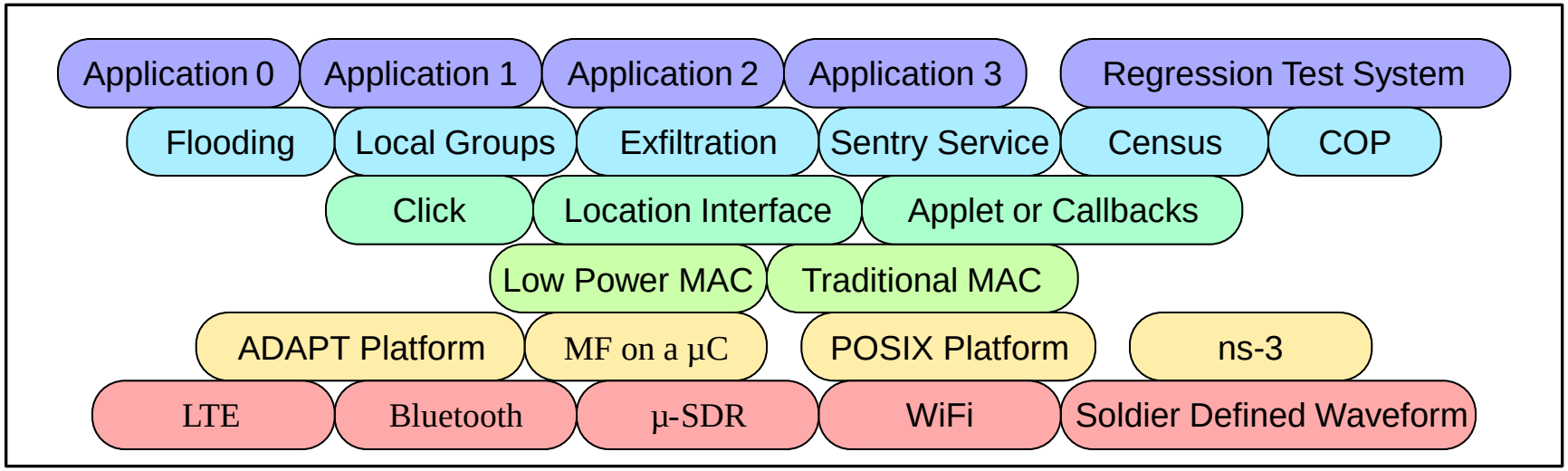
- **The concept:**
  - Define a RAL.
  - Write ASNP code to the RAL spec.
  - Easy to port to new platforms.
- **We choose to build the RAL on the open source *click* product.**
  - Click is not used for simulation.
  - Only used as a kind of router "VM".
- **Ported our RAL to ns3.**
  - Creates a regression test system.
  - Runs the actual field code in the emulation environment.
- **Facilitates rapid iteration throughout the life cycle.**
  - Facilitates time as a source of competitive advantage.



Candidate Patterns

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- **Flooding with pruning:**
  - Flood outward, terminating flood based on application defined criteria.
  - Hard to do in traditional paradigm.
    - *In order to send message to everyone in region you need to first know who's where.*
    - *Also less efficient in the traditional paradigm.*
- **Local emergent groups:**
  - Nodes elect to join a small local group.
  - Run traditional MANET over this small group embedded in the network.
  - Fully dynamic and emergent groups.
- **Exfiltration:**
  - Messages originating from any node are sent to one of the gateway nodes.
  - Maintaining routes to a single gateway is much lower cost than to every node.
- **Sentry service:**
  - Nodes form local groups with leaders.
  - The leader provides group services.
  - As nodes move they change groups.
- **Census:**
  - Count all the nodes in a region.
  - Generalizations of counting, like sum all the fuel in a region, are supported.
  - Hard to do in traditional paradigm.
    - *Have to know who's around in order to send them a message to ask them if they are around.*
- **Common Operational Picture (COP):**
  - Classic military application.
  - The ASNP offers routing aware COP.
    - *More efficiently than in the traditional paradigm.*

Exfiltration Example

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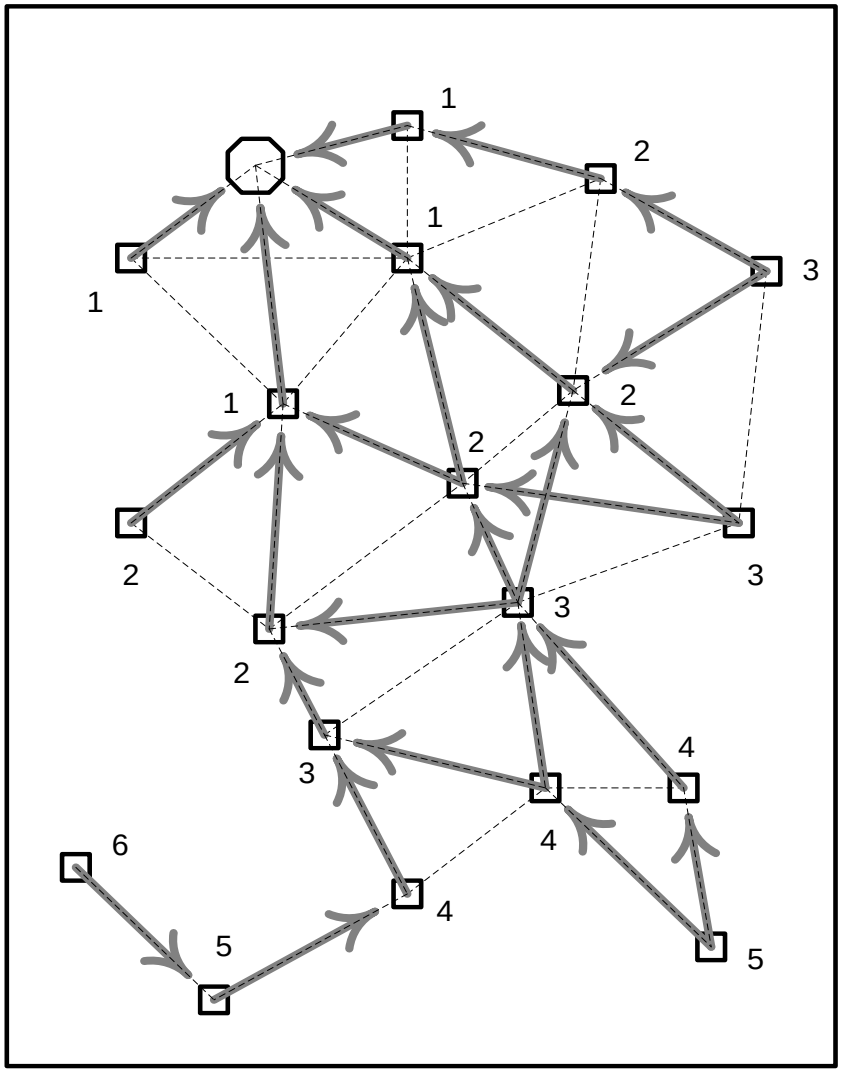
- **Maintain a tree routing structure pointing back to the gateway.**
- **Why this works:**
  - Mobility will frequently break routes.
  - But, repairs are fast and low cost.
- **Notes:**
  - Breaks can be locally detected.
  - Repairs are mostly local.
  - Routes may become suboptimal, but the is a small affect compared to the overhead advantages.
  - Many variants, like multi-parent trees.
- **In emulation, seems to scale to thousands of nodes.**



Advertisement

System of Systems Considerations

- **The Internet is not a system.**
- **It's success is as a system of systems or as an ecosystem.**
- **Any creditable counter-part must be evaluated as ecosystem.**

Part III

A System of System Oxymoron

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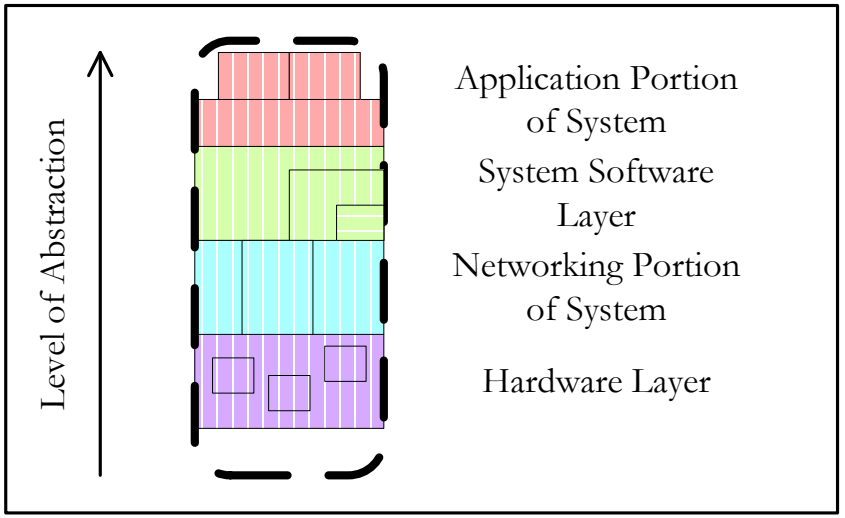
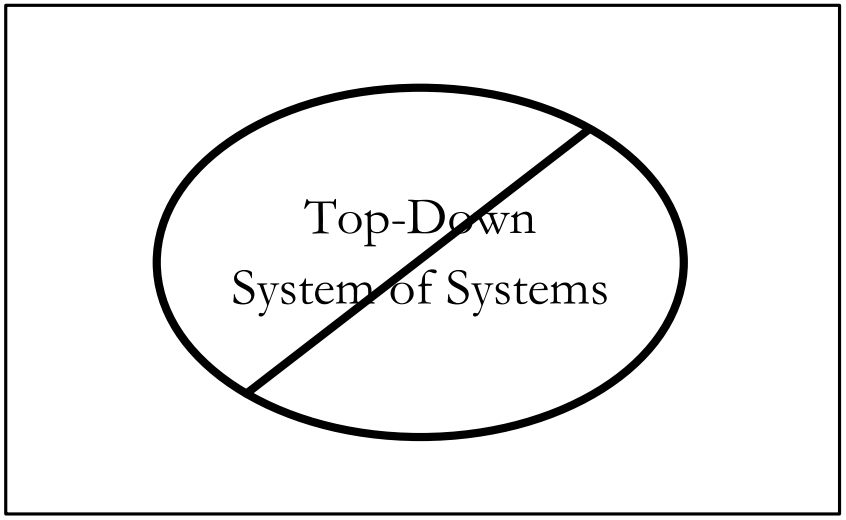
- **Top-down methodology:**
  - Simply decomposes requirements and responsibility, recursively.
  - Until each person knows what to do for the next unit of work.
- **Systems of systems concept is incompatible with pure top-down.**
  - Internal boundaries are somewhat arbitrary, i.e., not core to the design.
- **In a stove pipe world you can't do systems of systems.**

ASNPS should not be a pure stove pipe.





Vertical and Horizontal Integration

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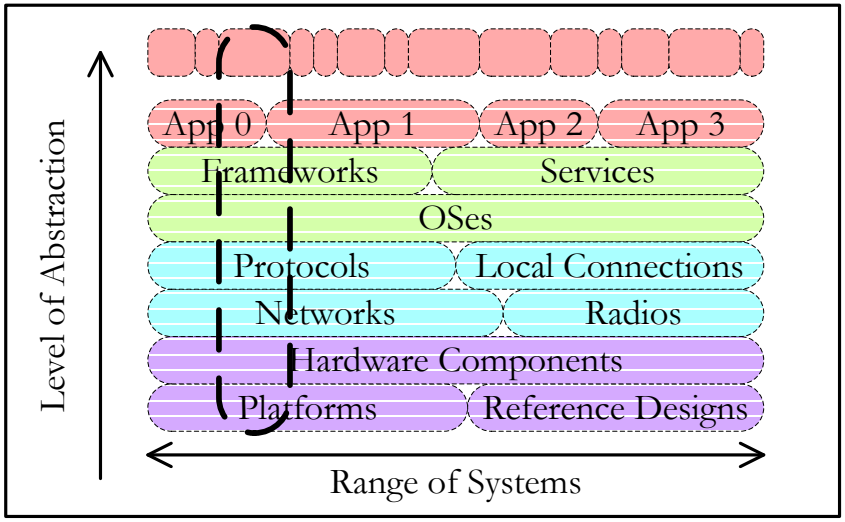
- **Stove Piping is just vertical integration.**
  - Most elements are custom built for the specific application.
  - Facilitates far greater optimization of end-to-end performance.

- **Christenson defines the opposite of this as horizontal integration.**
  - Most elements are used across all applicants.
  - Facilitates far greater flexibility, economy, and design speed.



Integration Direction and Life Cycle

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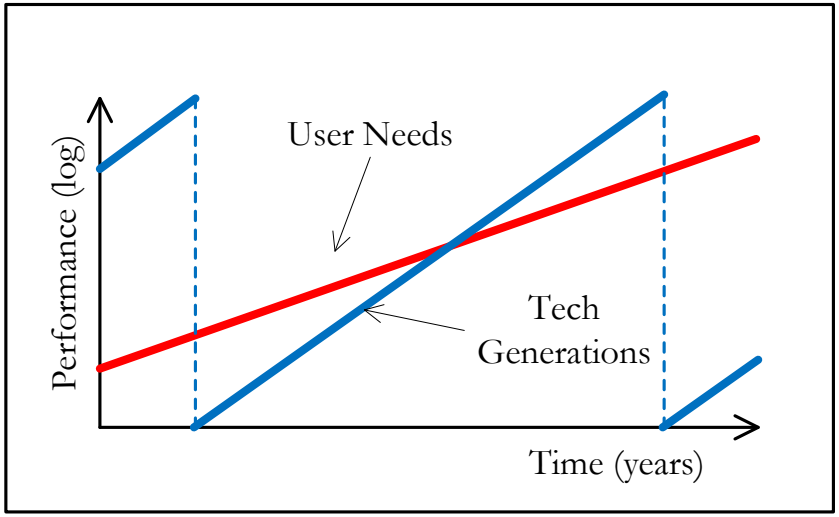
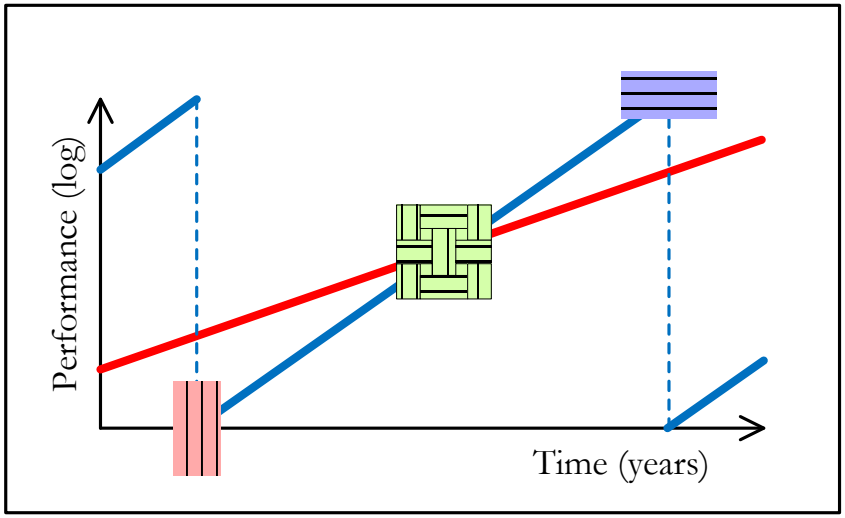
- **Christenson further argues that over the technology life cycle the needs shift.**

- **As a result the direction of integration should change to:**
  - New tech needs vertical integration.
  - Old tech needs horizontal integration.
  - Mainstream tech needs a complex mixture of vertical and horizontal.





Robust Ecosystems Need a Waist

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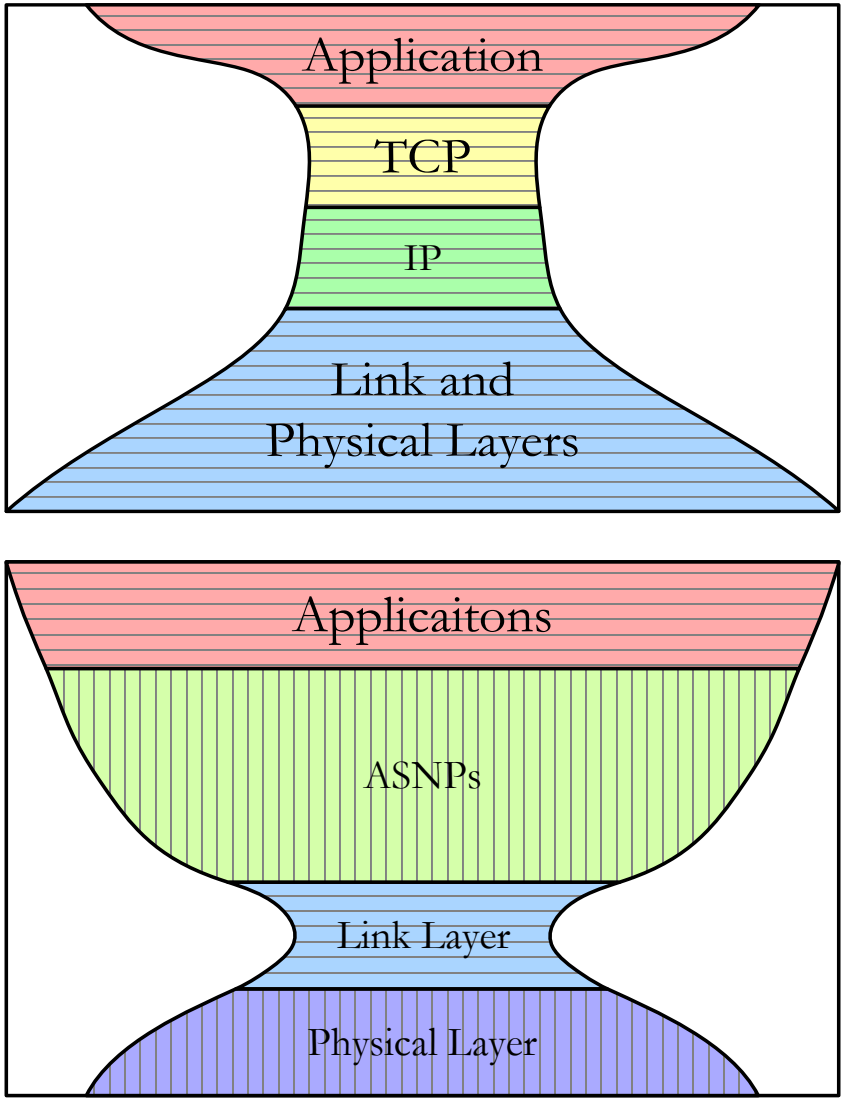
- **Complexity theorist believe that robust systems need a waist.**
  - Although the argument seems (to me) to be mostly based on analogy.
- **Without standardization it's not possible to mix and match parts.**
  - Breadth above and below the waist is facilitated by the standardization of the narrowness of the waist.
- **Eli Whitney is credited with the concept of interchangeable parts.**
  - May be the first U.S. defense research transition successes story.

However, the waist is a very horizontal part of the system.

Our Position

- **An attractive rationalization of the success of the internet is:**
  The "waist" facilitated extreme flexibility in the rest of the ecosystem.
- **Mobility changes the problem.**
  - The performance of the networking layer becomes a hard problem.
  - This issue is fundamental and unlikely to abate for a generation.
- **The "problem" with MANETs is the use of the Internet's ecosystem architecture.**
  - Maximal horizontal integration at a point of great performance shortfall.

ASNPs are "the how" for lowering the waist.



The Adjacent Possible

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- **These are big ideas.**
  - This should give us some pause.
- **Innovations need to be broken into sequences of "single" steps.**
  - See the book, *Where Good Ideas Come From*, by Steven Johnson.
  - "When innovating the shortest path between two points is rarely a straight line", Jim Balsillie.
- **What is the next step?**
- **Some vertical applications that don't have to support everything.**
  - COP.
  - Tactical census applications.
  - Networks of active tags for logistics.
- **Auxiliary system, that adds value, but can be incomplete.**
  - Tactical blogging; maybe delay tolerant.
  - Sensors for sociological intelligence.
- **Overtly civilian applications that develop the technology first.**
  - Communications for civilians in war zones (or refugees).
  - Peer-to-peer cell phone apps that avoid using the cellular service.

Issues

Appendix I

Fake Issues

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Security:

- **This is a TRL issues.**
  - Not a fundamental problem.
- **In fact we expect some security advantages to ASNPs.**

Completeness:

- **We do not strive for a complete set of ASNPs.**
- **This is no longer the waist.**
  - We only strive for a high reuse.

Polymorphism:

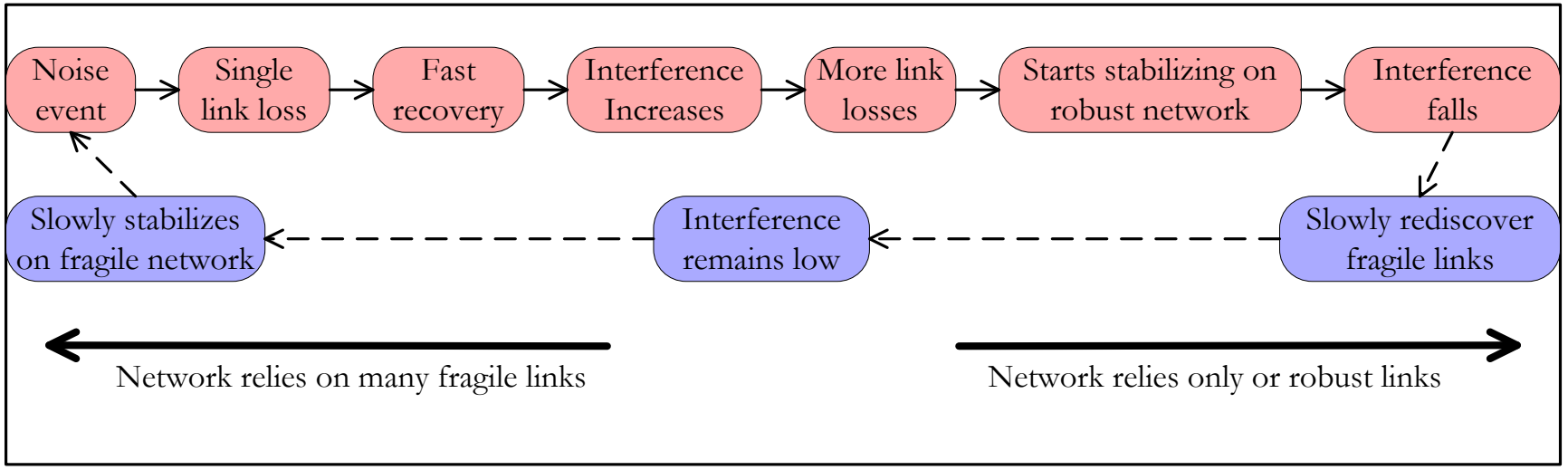
- **We advocate naming ASNP instances.**
  - Will require a naming service.
  - Traffic would be tages according to its ASNP instance.
- **Vaguely like *Named Data Networking*.**

Existing Traffic Statistics:

- **Studies show that most traffic is local, even today.**
- **But most applications will be re-optimized for ASNPs.**
  - Changing the traffic statistics

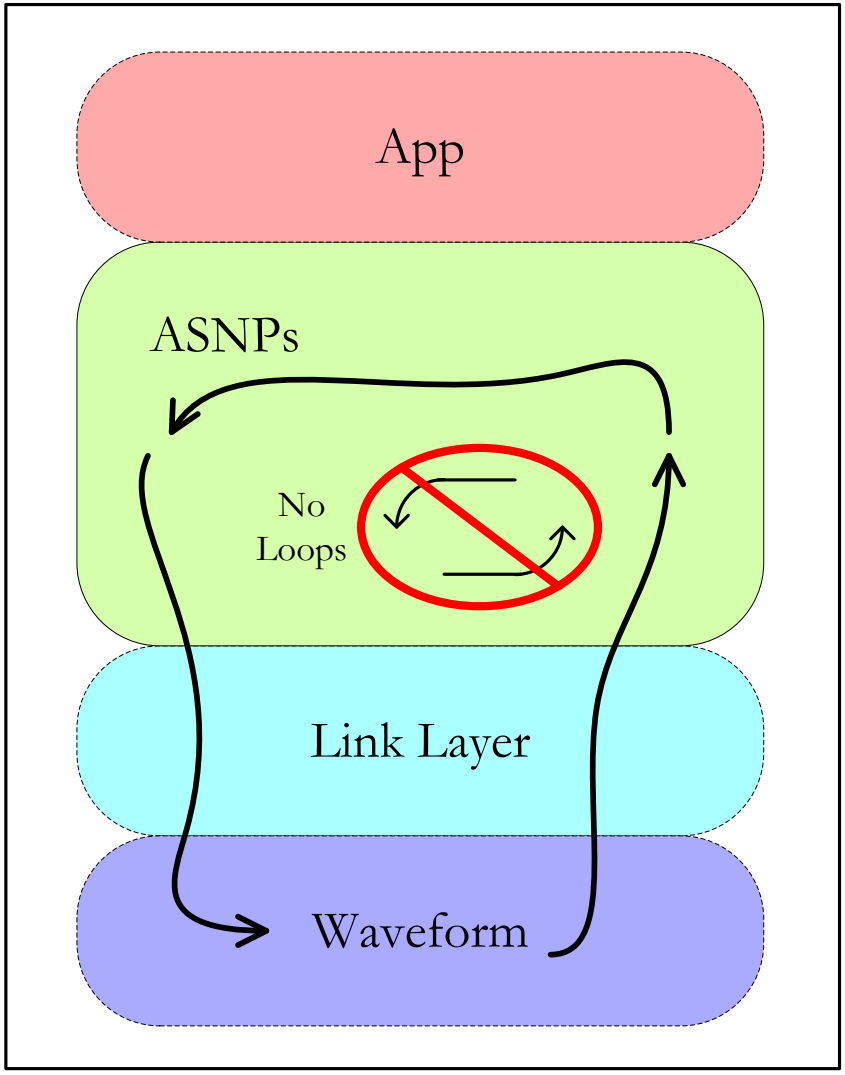
Stability: Example

- **We had an exfiltration ASNP that we thought should be stable.**
  - We were, in fact, cleaning up the details on the proof.
- **We implemented it.**
  - Even without motion it was not stable.
  - That is, even a static network would never stabilize.
- **Problem interaction between link detection and higher layers.**
  - Exacerbated by rapid repair, slow optimize, policy.



Stability: Implications

- **We had inter-layer feedback.**
  - No loop within the ASNP layer.
- **How do deal with this in the real world …**
- **The people problem:**
  - Designer had assumptions that the implementer violated.
  - The implementer didn't understand feedback or stability theory.
  - These are not easy to state.
  - They are every hard to validate.
- **We don't have a solution.**



Reading List

Appendix I

Larger than Systems Architectures

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The adjoining three books are recommended as introductions to ecosystem architecture.

They have a business ecosystem focus. This makes them more accessible than many books on systems of systems, because they assume very little domain specific knowledge. In addition business books tend to be more seminal, more authoritative, and more tutorial. This is partly an advantage of abstraction; but abstraction is also the potential weakness of this genre.

- **The Great Transition**

  By Martin.

  A seminal work on a wide range of implications of switching away from stove pipe architectures and stove pipe organizations.

- **Seeing What's Next**

  By Christenson.

  Influential early work on vertical and horizontal integration. Argues that each is optimizing for different needs and that each is needed at different times and in different parts of the ecosystem.

- **Clock Speed**

  By Fine.

  Argues that complex value chains tend towards a nested mosaic of horizontal and vertical integration. Focuses on the development speed implications of integration direction decisions.